International Journal of Mechanical and Production Engineering Research and Development IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 4, Aug 2019, 629-636

BUCKLING ANALYSIS OF THIN FRP LAMINATE UNDER COMBINED THERMAL AND MECHANICAL LOADING

B. SREENIVASA RAO[1*], G. SAMBASIVA RAO[2] & J. SURESH KUMAR[3]

[1]*Assistant Professor, Department of Chemical Engineering, V.R. Siddhartha Engineering College, Vijayawada, India*

[2]*Principal, Sir C R Reddy College of Engineering, Eluru, India*

[3]*Professor, Department of Chemical Engineering, Jawaharlal Nehru Technological University, Hyderabad, India*

ABSTRACT

Thermal environment influences the buckling behavior of structures, in addition to the mechanical loads acting on it. The present work aims to predict the buckling load factor of thin FRP laminates subjected to pressure and temperature loads. The problem of thin FRP laminate in the form of rectangle is simulated in finite element software ANSYS using 2-D finite element method that works on classical lamination theory. Two different stacking arrangements; (i) symmetric cross ply and (ii) symmetric quasi-isotropic of E-Glass-Epoxy with Fiber volume fraction, V_f = 0.55 and Kevlar-Epoxy with Fiber volume ratio, V_f = 0.60 are considered in the analysis, and the influence of in-plane aspect ratio (AR) and thickness ratio (TR) on buckling factor is studied.

KEYWORDS: Thin Laminate, FEM, FRP, Thermoelastic & Buckling

Received: May 20, 2019; **Accepted**: Jun 10, 2019; **Published**: Jul 06, 2019; **Paper Id.**: IJMPERDAUG201962

Original Article

INTRODUCTION

FRP laminates are preferred over metallic structure at several applications due to their high specific strength and high specific stiffness. In most of the cases, FRP structures are thin and therefore need to check for any possibility of buckling. Due to change in environment, structures may be subjected to thermal loads in addition to mechanical loads. So it is necessary to analyze the behaviour of structures under combined loads. Jaehong Lee [1] presented a layer wise theory for the prediction of buckling behaviour of laminated composites under thermal loads, using finite element method. Omer Sinan Sahin et al [2] carried out studies on thermal buckling of hybrid material angle-ply thin layered composite plates with a hole. Sreenivasa Rao et al [3] analyzed buckling of a thin FRP laminate under temperature load. Sreenivasa Rao et al [4] analyzed static vs. buckling failure mode of a thin FRP laminate under temperature load. Sreenivasa Rao et al [5] analyzed the influence of material properties on failure mode of thin FRP laminate under thermal loading. Lakshmi Narayana et al [6] carried out studies on thermal buckling behaviour of laminated composite plate with square/rectangular cutout having different volume fractions. Present analysis is the extension of Sreenivasa Rao et al [3] for combined temperature and pressure loads on E-Glass-Epoxy laminate and Kevlar-Epoxy laminate.

Problem Modeling

Geometry of the laminate is a rectangular plate with length ‘a’ = 2 m, width ‘b’ =1 m and thickness ‘t’ = 0.020 m as shown in Figure 1. Laminate consists of eight number of layers of uniform thickness and with different orientations i) Symmetric Cross-ply (0/90/90/0/0/90/90/0) and ii) Symmetric quasi isotropic

(90/45/-45/0/0/-45/45/90). In this study, shell 281 of ANSYS software [7] is selected as the element type which consists of 8 nodes with six dof at each node. This element is capable of quadratic interpolation and is developed based on classical lamination theory. This element is suitable for analyzing thin to moderately thick structures and well suited for layered composites. Left end of the plate is clamped and five dof are constrained along other three sides. X- Directional displacement is kept free on these sides to permit to respond to the axially applied pressure load of 1 Pa along right side of the plate (Figure 1).

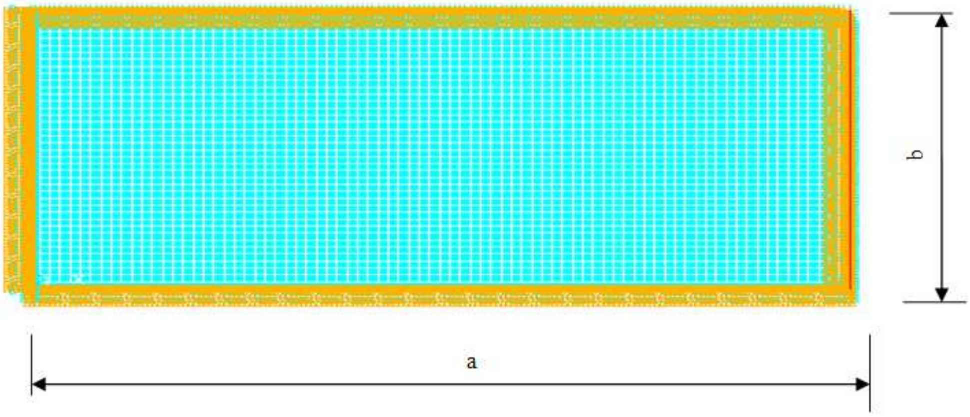

Figure 1: Geometry and Meshed Model of Laminate with AR=2

Following properties of E-Glass-Epoxy with Fiber volume ratio, V_f = 0.55 are taken from the reference [8].

E_1= 41 G Pa E_2 = 10.4 G Pa E_3 = 10.4 G Pa ν_{12} = 0.28 ν_{23} = 0.50 ν_{13} = 0.28

G_{12} = G_{13}=4.3 G Pa G_{23}=3.5 G Pa

Coefficient of linear expansion: $\alpha_1 = 7 \times 10^{-6}/^0C$, $\alpha_2 = \alpha_3 = 26 \times 10^{-6}/^0C$.

Following properties of Kevlar-Epoxy with Fiber volume ratio, V_f = 0.60 are taken from the reference [8].

E_1= 80 G Pa E_2 = 5.5 G Pa E_3 = 5.5 G Pa ν_{12} = 0.34 ν_{23} = 0.40 ν_{13} = 0.22

G_{12} = G_{13}=2.2 G Pa G_{23}=1.8 G Pa

Coefficient of linear expansion: $\alpha_1 = -2 \times 10^{-6}/^0C$, $\alpha_2 = \alpha_3 = 6 \times 10^{-6}/^0C$.

ANALYSIS OF RESULTS

Finite element mesh is refined to obtain converged results. The converged results are verified for isotropic material (Steel) for buckling factor under pure temperature load, as provided in reference [9]. The comparison is shown in Table 1

Table 1: Validation of FE Model for Isotropic Material (Steel) for AR =2

(t/b)	Element Length	Theoretical [9]	Present	% Variation
0.05	25 mm	28.2 °C	28.5 °C	1.06

First five buckling modes of the symmetric cross-ply laminate with a/b = 2.0 are shown in Figure 2. The systematic deformations that appear in the contours ensure proper modelling of the problem in terms of constrains and loading.

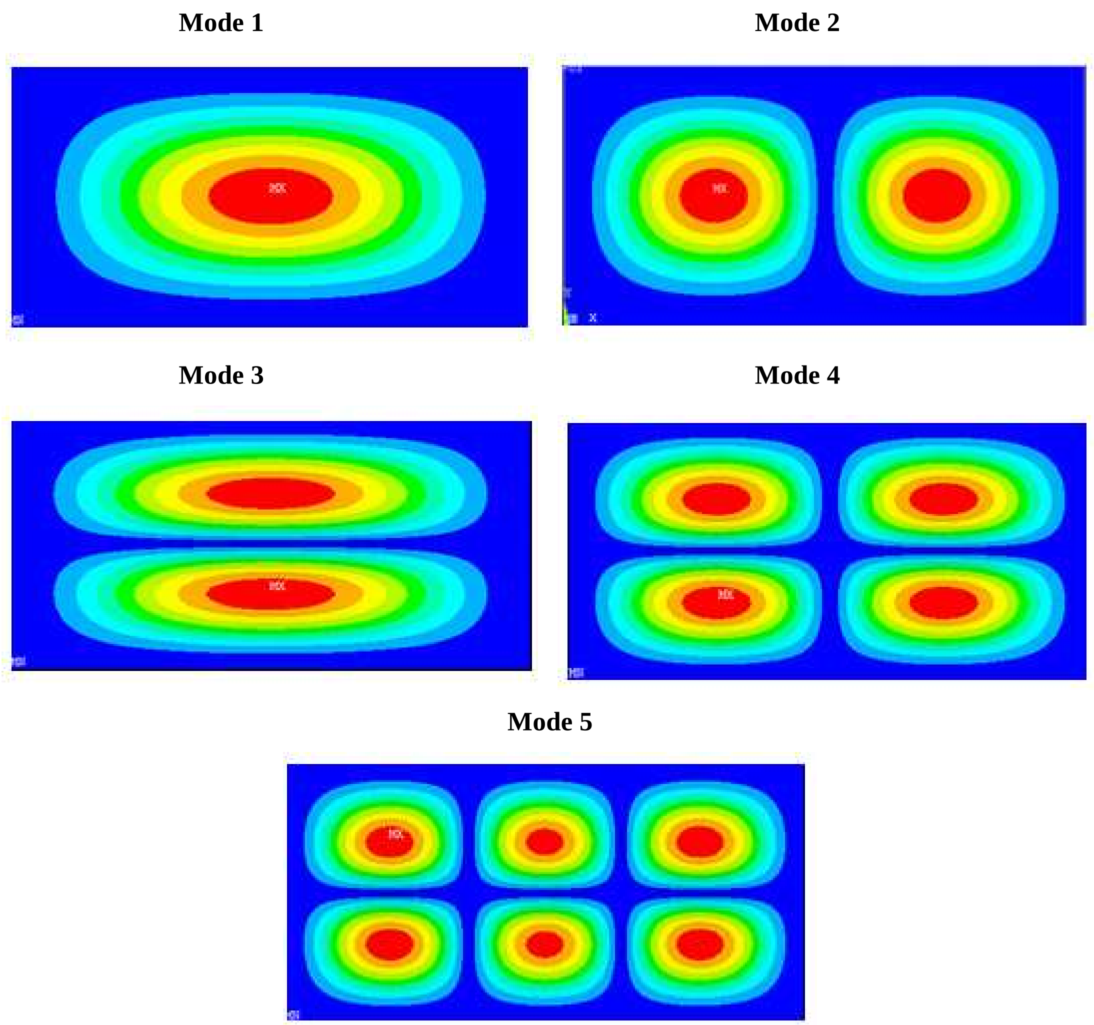

Figure 2: Buckling Modes of Symmetric Cross-Ply Rectangular Laminate with AR=2 and TR=100

Effect of Aspect Ratio

Variation of first mode buckling factor, with respect to aspect ratio in E-Glass-Epoxy laminates is shown in Figures 3 and 4 for cross-ply and quasi isotropic arrangements respectively. In both the cases, increase in AR causes for reduction in buckling factor indicating that reduction in load capacity. This is as expected, due to reduction in stiffness of the laminate with increase in AR. It is also observed that buckling factor in quasi isotropic laminates is higher when compared to cross-ply laminates. Number of layers with 90^0 orientations is less in quasi isotropic laminates resulting in increase in stiffness. Buckling factors are obtained for first five modes and these results for different values of AR are listed in Tables 2 and 3 for cross-ply laminates and quasi isotropic laminates, respectively. Variation of buckling factor with respect to AR at higher modes is observed to be similar to that in first mode. It is also observed that buckling factor increases with increase in mode number. Similar in case of mechanical vibrations, as the mode number increases, number of curvatures of deformed structure increases resulting in increase in overall stiffness of the structure.

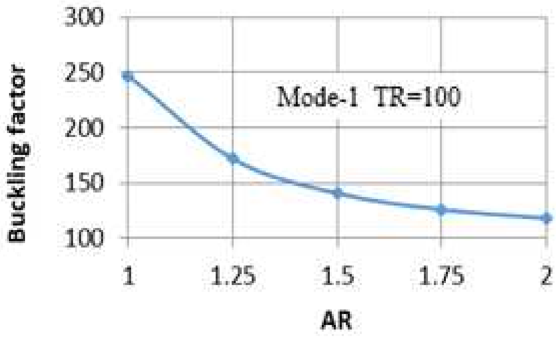

Figure 3: Variation of Buckling Factor with AR in Cross-Ply Laminates (E-Glass-Epoxy)

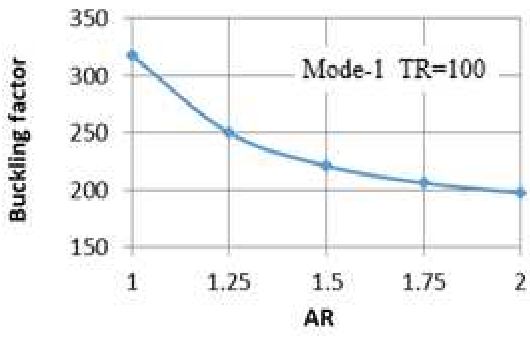

Figure 4: Variation of Buckling Factor with AR in Quasi Isotropic Laminates (E-Glass-Epoxy)

Table 2: Effect of Aspect Ratio on Buckling Factor in Cross-Ply Laminates (E-Glass-Epoxy)

AR	Buckling Factor				
	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
2.00	118.02	188.57	216.50	251.25	328.74
1.75	125.82	220.30	234.58	271.09	388.36
1.50	140.52	226.93	307.09	314.35	416.21
1.25	171.64	239.95	380.44	429.32	429.55
1.00	246.89	270.29	463.87	550.99	569.24

Table 3: Effect of Aspect Ratio on Buckling Factor in Quasi Isotropic Laminates (E-Glass-Epoxy)

AR	Buckling Factor				
	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
2.00	197.84	274.62	373.30	415.76	454.01
1.75	206.33	317.71	379.95	447.89	569.04
1.50	221.16	379.75	406.03	492.06	704.44
1.25	250.28	403.08	551.98	572.64	727.52
1.00	317.80	439.11	740.13	770.89	824.91

Variation of first mode buckling factor with respect to aspect ratio in Kevlar-Epoxy laminates is shown in Figures 5 and 6 for cross-ply and quasi isotropic arrangements, respectively. Buckling factors for first five modes for different values of AR are listed in Tables 4 and 5 for cross-ply laminates and quasi isotropic laminates, respectively. Variation of buckling factor with respect to AR in these laminates is observed to be similar to that of E-Glass-Epoxy laminates. However, the buckling factor in these laminates is found to be about three times better than E-Glass-Epoxy laminates.

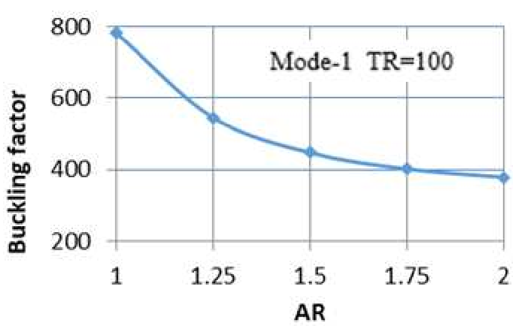

Figure 5: Variation of Buckling Factor with AR in Cross-Ply Laminates (Kevlar -Epoxy)

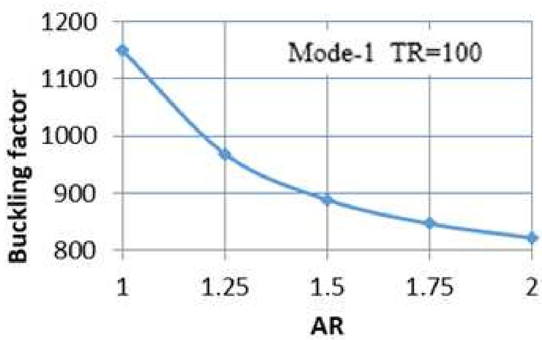

Figure 6: Variation of Buckling Factor with AR in Quasi Isotropic Laminates (Kevlar-Epoxy)

Table 4: Effect of Aspect Ratio on Buckling Factor in Cross-Ply Laminates (Kevlar-Epoxy)

AR	Buckling Factor				
	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
2	379.25	584.34	685.24	760.44	958.86
1.75	402.16	693.45	725.76	811.01	1124.60
1.5	447.13	708.87	907.78	959.97	1272.70
1.25	545.27	741.68	1113.20	1253.70	1306.40
1	781.74	824.54	1409.50	1587.90	1604.90

Table 5: Effect of Aspect Ratio on Buckling Factor in Quasi Isotropic Laminates (Kevlar-Epoxy)

AR	Buckling Factor				
	1st Mode	2nd Mode	3rd Mode	4th Mode	5th Mode
2	821.87	1042.20	1470.60	1529.00	1529.00
1.75	846.42	1159.80	1549.50	1680.00	1916.70
1.5	888.40	1359.20	1590.30	1844.60	2417.90
1.25	968.79	1583.40	1826.70	2076.40	2822.50
1	1150.20	1703.50	2542.70	2648.10	2926.10

Effect of Thickness Ratio

Variation of first mode buckling factor with respect to thickness ratio is shown in Figures 5 and 6 for cross-ply laminates and quasi isotropic laminates, respectively. In both the cases, increase in TR causes for reduction in buckling factor, indicating that reduction in load capacity. This is as expected due to reduction in stiffness of the laminate with decrease in thickness. It is also observed that buckling factor in quasi isotropic laminates is higher when compared to cross-ply laminates. Buckling factors are obtained for first five modes, and these results for different values of TR are listed in Tables 4 and 5 for cross-ply laminates and quasi isotropic laminates, respectively. Variation of buckling factor with respect to TR at higher modes is observed to be similar to that in first mode. It is also observed that buckling factor increases with increase in mode number.

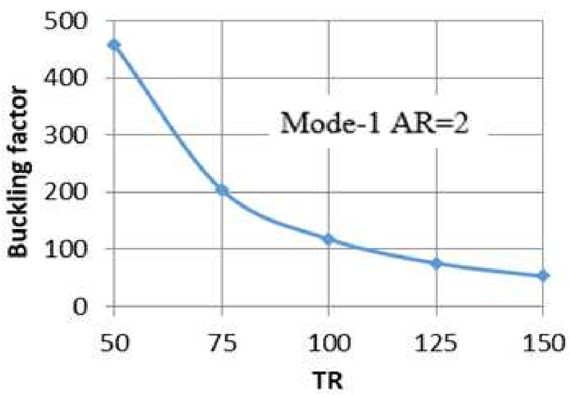

Figure 7: Variation of Buckling Factor with TR in Cross-Ply Laminates (E-Glass-Epoxy)

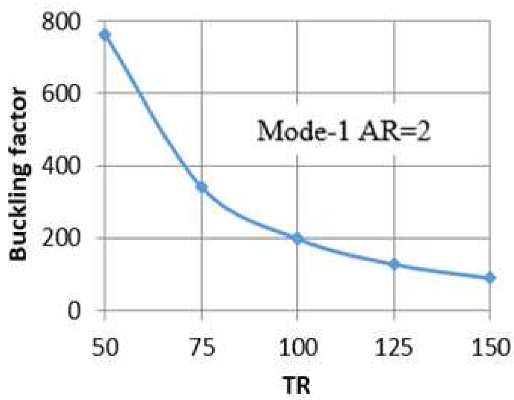

Figure 8: Variation of Buckling Factor with TR in Quasi Isotropic Laminates (E-Glass-Epoxy)

Table 6: Effect of Thickness Ratio on in Cross-Ply Laminates (E-Glass-Epoxy)

TR	Buckling Factor				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
150	52.98	84.73	97.91	113.64	148.78
125	75.83	121.23	139.77	162.21	212.33
100	118.02	188.57	216.50	251.25	328.74
75	203.99	325.55	370.60	430.04	562.22
50	457.18	726.90	807.65	937.05	1222.30

Table 7: Effect of Thickness Ratio on Buckling Factor in Quasi Isotropic Laminates (E-Glass-Epoxy)

TR	Buckling Factor				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
150	88.91	123.49	169.19	188.10	204.98
125	127.21	176.64	241.34	268.49	292.78
100	197.84	274.62	373.30	415.76	454.01
75	341.45	473.56	637.21	711.07	779.07
50	761.91	1054.10	1377.70	1543.60	1712.10

Variation of first mode buckling factor with respect to thickness ratio in Kevlar-Epoxy laminates is shown in Figures 9 and 10 for cross-ply and quasi isotropic arrangements, respectively. Buckling factors for first five modes for different values of TR are listed in Tables 8 and 9 for cross-ply laminates and quasi isotropic laminates, respectively. Variation of buckling factor with respect to TR in these laminates is observed to be similar to that of E-Glass-Epoxy laminates. However, the buckling factor in these laminates is found to be about three times better than E-Glass-Epoxy laminates.

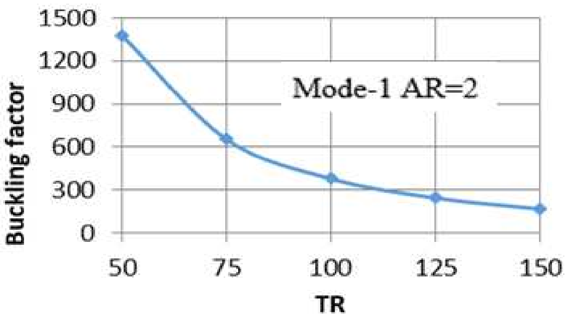

Figure 9: Variation of Buckling Factor with TR in Cross-Ply Laminates (Kevlar-Epoxy)

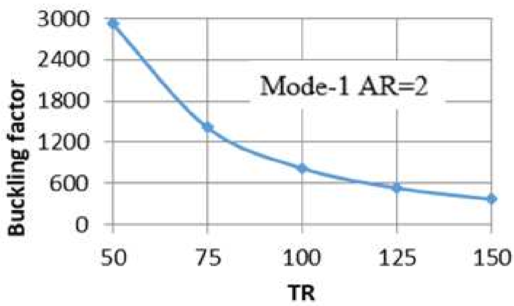

Figure 10: Variation of Buckling Factor with TR in Quasi Isotropic Laminates (Kevlar-Epoxy)

Table 8: Effect of Thickness Ratio on in Cross-Ply Laminates (Kevlar-Epoxy)

TR	Buckling Factor				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
150	170.41	262.97	315.28	349.33	440.06
125	245.69	378.94	450.66	499.62	629.61
100	379.25	584.34	685.24	760.44	958.86
75	655.80	1008.00	1149.40	1278.20	1613.50
50	1378.20	2101.80	2240.80	2506.00	3169.50

Table 9: Effect of Thickness Ratio on Buckling Factor in Quasi Isotropic Laminates (Kevlar-Epoxy)

TR	Buckling Factor				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
150	370.98	471.01	667.85	708.87	797.84
125	533.99	677.70	959.30	1010.40	1137.70
100	821.87	1042.20	1470.60	1529.00	1723.20
75	1412.60	1788.50	2504.70	2540.40	2871.00
50	2922.80	3686.10	4845.30	5024.00	5557.90

CONCLUSIONS

Eight layered E-Glass-Epoxy and Kevlar-Epoxy laminates are analyzed for their buckling resistance under combined mechanical and thermal loads, using classical lamination theory based finite element method. Following observations are drawn from the present study

- Buckling factor decreases with increase in AR, TR
- Buckling factor increases with increase in mode order
- Quasi isotropic laminates show relatively better performance when compared to cross-ply laminates
- Kevlar-Epoxy laminates show about three times better performance when compared to E-Glass-Epoxy laminates

REFERENCES

1. *Jaehong Lee, Computers & Structures, 65, (1997), 917-922*
2. *O¨mer Sinan S_ahin et al, Composites Science and Technology 65(2005), 1780-1790*
3. *B. SrinivasaRao, G. SambasivaRao, J. Suresh Kumar, Materials Today: Proceedings 5 (2018) 12803-12813*
4. *Lakshmi narayana et al, Materials Today: Proceedings5 (2018) 5819-5829*
5. *ANSYS Reference Manuals 2016.*
6. *Isaac M.D. and Orilshai, "Engineering Mechanics of Composite Materials", Oxford University Press, 2006.*
7. *http://www.engr.uconn.edu/~cassenti/AnsysTutorial/Modules_APDL/Module%207%20Thermal_Buckling.pdf*
8. *Sawant, S. M., & Hujare, D. P. (2013). Thermo-mechanical analysis for skirt of pressure vessel using FEA approach. International Journal Of Mechanical Engineering (IJME) ISSN, 2319-2240.*